COS 318: Operating Systems

Security

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(http://www.cs.princeton.edu/courses/cos318/)

Security

- The security environment
- Basics of cryptography
- User authentication
- Attacks in a non-networked world
- Attacks in a networked world

2

Security Goals and Threats

- Operating systems have goals
  - Confidentiality, Integrity, Availability, Exclusion of outsiders
- Someone attempts to subvert the goals
  - Fun or accomplishment
  - Commercial gain

Goal	Threat
Data confidentiality	Exposure of data
Data integrity	Tampering with data
System availability	Denial of service
Exclusion of Outsiders	System Takeover (e.g. by viruses)

3

What kinds of intruders are there?

- Casual prying by nontechnical users
  - Curiosity
- Snooping by insiders
  - Often motivated by curiosity or money
- Determined attempt to make trouble, or personal gain
  - May or may not be an insider
  - Could even be just to show that they can do it
- Commercial or military espionage

4

Accidents cause problems, too…

- Fires, Earthquakes, Floods
- Hardware or software errors
  - CPU malfunction
  - Disk crash or bad disk
  - Program bugs
- Human errors
  - Data entry
  - Wrong tape mounted
  - rm *

5

How to Protect?

- Hardware?
  - Parity and error correction
  - Physical access
  - Hardware assistance for memory isolation/protection
  - Timers
  - …
- OS?
  - Process isolation, scheduling, encryption, privileges, passwords
- Communication protocols?

Key Aspects of Security

- **Authentication**
  - Who is the user, and are they who they say they are?
- **Authorization**
  - Who is allowed to do what?
- **Enforcement**
  - Make sure people do only what they are supposed to do

Loophole in any of these means there is a problem:

1. Authentication: Login as another user and you have circumvented authentication Login as super user and you have circumvented authentication
2. Authorization: Login as self and you can do anything to your own resources. What if you run aprogram that decides to erase all your files? What if system allows you to delete/modify another user's files?
3. Enforcement: Can you trust the system to correctly enforce decisions about 1+2?

User Authentication

- Problem: how does the computer know who you are?
- Solution: Use *authentication* to identify:
  - Something the user knows
  - Something the user has
  - Something the user is
- This must be done before user can use the system
- Important: from the computer's point of view…
  - Anyone who can duplicate your ID *is* you
  - Fooling a computer isn't all that hard…

8

Authentication

- Common approach: passwords. Shared secret between you and the machine --- since only you know the password, machine can assume it is you.
- Private key encryption --- use an encryption that can be easily reversed if given the correct key (and is very hard to reverse without the key)
- Public key encryption --- an alternative (that separates authentication from secrecy)

Authentication using Passwords

```
Login: elm
Password: foobar

Welcome to Linux!
```

```
Login: jimp
User not found!

Login:
```

```
Login: elm
Password: barfle
Invalid password!

Login:
```

- Successful login lets the user in
- If things don't go so well…
  - Login rejected after name entered
  - Login rejected after name and incorrect password entered
- Don't notify the user of incorrect user name until *after* the password is entered!
  - Early notification can make it easier to guess valid user names

10

Sample Breakin (from LBL)

```
LBL> telnet elxsi
ELXSI AT LBL
LOGIN: root
PASSWORD: root
INCORRECT PASSWORD, TRY AGAIN
LOGIN: guest
PASSWORD: guest
INCORRECT PASSWORD, TRY AGAIN
LOGIN: uucp
PASSWORD: uucp
WELCOME TO THE ELXSI COMPUTER AT LBL
```

Lesson: change all the default system passwords!

11

Dealing with Passwords

- Passwords should be memorable
  - Users shouldn't need to write them down
  - Users should be able to recall them easily
- But they should also be long and obscure
  - So one cannot exhaustively list and determine
  - Unix initially required only 5-letter lowercase passwd
  - Exhaustive search: 26^5 = 10 million to try
    - In 1975, 10ms per passwd => one day
    - In 2015, less than 10ms for entire search/check
  - Just using English words makes checking even easier (use dictionary)

12

Dealing with Passwords

- Passwords shouldn't be stored by system "in the clear"
  - Password file is often readable by all system users
  - Password must be checked against entry in this file
  - What if malicious user gets access to password file?
- Solution: use hashing to hide "real" password
  - One-way function converts password to meaningless string of digits (Unix password hash, MD5, SHA-1)
  - Difficult to find another password that hashes to the same random-looking string
  - Knowing the hashed value and hash function gives no clue to the original password

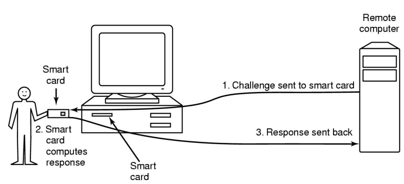
13

Salting the passwords

- Hashing is not enough
  - Hackers can get a copy of the password file
  - Run through dictionary words and names for possible passwords
    - Hash each name
    - Look for a match in the file
- Solution: use a "salt"
  - Random characters added to the password before hashing
  - Increases the number of possible hash values for a given password
    - Actual password is "pass"
    - Salt = "aa" => hash "passaa"
    - Salt = "bb" => hash "passbb"
  - Result: password cracker has to try many more combinations

14

Authentication using a physical object

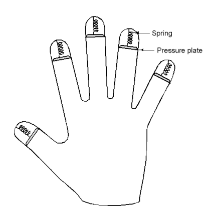


- Magnetic card
  - Stores a password encoded in the magnetic strip
  - Allows for longer, harder to memorize passwords
- Smart card
  - Card has secret encoded on it, but not externally readable
  - Remote computer issues challenge to the smart card
  - Smart card computes the response and proves it knows the secret

15

Authentication using biometrics

- Use basic body properties to prove identity
- Examples include
  - Fingerprints
  - Voice
  - Hand size, finger length
  - Retina patterns
  - Iris patterns
  - Facial features
  - Image analysis, gait analysis
- Potential problems
  - Duplicating the measurement
  - Stealing it from its original owner?



16

Counter Measures

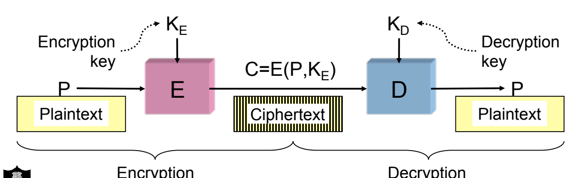
- Limiting times when someone can log in
- Automatic callback at pre-specified number
- Limited number of login tries
- Simple login name/password as a trap
  - Security personnel notified when attacker bites

Cryptography

- Goal: keep information from those who aren't supposed to see it
  - Do this by "scrambling" the data
- Use a well-known algorithm to scramble data
  - Algorithm has two inputs: data & key
  - Algorithms are publicly known
  - Key is known only to "authorized" users
- Cracking good codes is ***very*** difficult. But possible

Cryptography Basics

- Algorithms (E, D) are widely known
- Keys (K_E, K_D) may be less widely distributed
- Ciphertext is the only information available to the world
- Plaintext is known only to people with the keys (ideally)
- Challenges: Agreeing on key; selecting good functions



Modern Encryption Algorithms

- Data Encryption Standard (DES)
  - Uses 56-bit keys
  - Same key is used to encrypt & decrypt
  - Keys used to be difficult to guess
    - Modern computers can try millions of keys per second with special hardware
    - For $250K, EFF built a machine that broke DES quickly
- More recent algorithms (AES, Blowfish) use 128 bit keys
  - Adding one bit makes it twice as hard to guess
  - Must try 2^{127} keys, on average, to find the right one
  - At 10^{15} keys per second, this would require over 10^{21} seconds, or 1000 billion years!
  - Modern encryption isn't usually broken by brute force

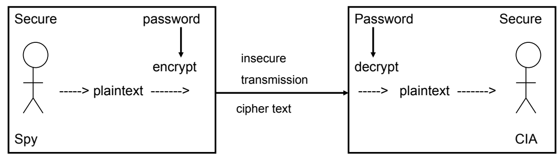
Unbreakable Codes?

- There *is* such a thing as an unbreakable code
  - Use a truly random key, as long as the message to be encoded
  - XOR the message with the key a bit at a time
- Code is unbreakable because
  - Key could be anything
  - Without knowing key, message could be anything that has the correct number of bits in it
- Difficulty: distributing key is as hard as distributing msg
- Difficulty: generating truly random bits
  - May use physical processes: radioactive decay, leaky diode, etc.
    - Lava lamp (!) [http://www.sciencenews.org/20010505/mathtrek.asp]

21

Private Key Cryptography

- Two roles for encryption
  - Authentication
  - Secrecy --- I don't want anyone to see these data



- From cipher text, cant derive plain text (decode) without passwd
- From plain text and ciper text, can' t derive password!

Private Key Cryptography (contd.)

- How do you get shared secret in both places ? Use an *authentication server* (example: Kerberos)
- Main idea:
  - Server keeps list of passwords, provides a way for parties, A and B, to talk to one another, as long as they trust server.
- Notations
  - K_{xy} is a key for talking between x and y
  - K[…] means encrypt message […] with the key K

Example: Using an Authentication Server

- A asks server for key
  A → S (Hi, I'd like a key for talking between A and B)
- Server returns special session key encrypted with B's key
  S → A **Ksa[** use Kab; **Ksb[** This is A! Use Kab**]]**
- A gives B the ticket
  A → B **Ksb[** This is A! Use Kab **]**
- Plus a bunch of details:
  - Time-stamps to limit key usage and prevent replay
  - Encrypted checksums to prevent malicious user from changing message

Public Key Cryptography

- What if A and B don't share a trusted authentication server?
- Use **public key encryption** --- each key is now a pair **(Kpublic, Kprivate)**
- With private key system (it is symmetric!)
  K[text] = ciphertext   K[ciphertext] = text
- With public key system
  Kpublic[text] = ciphertext   Kprivate[ciphertext] =text
  Kprivate[text] = ciphertext'   (not same ciphertext as above)
  Kpublic[ciphertext'] = text
- Usually, for secrecy: public key for encryption, private for decryption
- Can't derive Kpublic from Kprivate and vice versa
  Kprivate kept secret, Kpublic put in a telephone directory

Example: using public key encryption

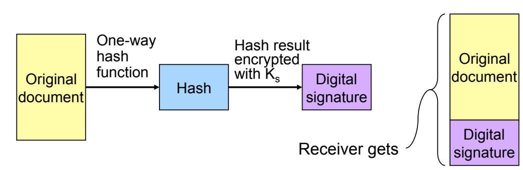
- Authentication:
  Kprivate[I am Anthony! **]**
  Everyone can read it, with my public key, but only I can send it!
- Secrecy:
  Kpublic [Hi! **]**
  Anyone can send it, but only the target can read it (with their private key)
- Secure communication
  Kpublic [Kprivate [I am Anthony! **]** Hi! **]**
  Only I can send it, and only you can read it!

One-way functions

- Function such that
  - Given formula for f(x), easy to evaluate y = f(x)
  - Given y, computationally infeasible to find x such that y = f(x)
- Often, operate similarly to encryption algorithms
  - Produce fixed-length rather than variable output
- E.g. cryptographic hash functions
  - MD5: 128-bit result
  - SHA-1: 160-bit result

27

Digital signatures



- Digital signature computed by
  - Applying one-way hash function to original document
  - Encrypting result with sender's *private* key
- Receiver can verify by
  - Applying one-way hash function to received document
  - Decrypting received signature using sender's public key
  - Comparing the two resulting signatures: equality means document unmodified

28

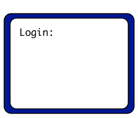
Pretty Good Privacy (PGP)

- Uses public key encryption
- Problem: public key encryption is very slow
- Solution: use public key encryption to exchange a shared key
  - Shared key is relatively short (~128 bits)
  - Message encrypted using symmetric key encryption
- PGP can also be used to authenticate sender
  - Use digital signature and send message as plaintext

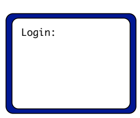
Attacks on computer systems

- Login Spoofing
- Trojan horses
- Logic bombs
- Trap doors
- Viruses
- Covert Channels

Login spoofing



Real login screen



Phony login screen

- No difference between real & phony login screens
- Intruder sets up phony login, walks away
- User logs into phony screen
  - Phony screen records user name, password
  - Phony screen prints “login incorrect” and starts real screen
  - User retypes password, thinking there was an error

Trojan horses

- Free program made available to unsuspecting user
  - Actually contains code to do harm
  - May do something useful as well…
- Place altered version of utility program on victim's computer
  - Trick user into running that program

Logic bombs

- Programmer writes (complex) program
  - Wants to ensure that he's treated well
  - Embeds logic "flaws" that are triggered if certain conditions are met or certain things aren't done
  - E.g. if I'm terminated and my record is deleted from employee db
  - E.g. if my salary isn't increased by at least 10% by March 25
  - E.g. if I don't enter my password for a few days
- In those situations
  - Program simply stops working
  - Program may even do damage
    - Overwriting data
    - Failing to process new data (and not notifying anyone)
- Programmer can blackmail employer
- Needless to say, this is highly unethical

33

Trap doors

```
while (TRUE) {
  printf (“login:”);
  get_string(name);
  disable_echoing();
  printf (“password:”);
  get_string(passwd);
  enable_echoing();
  v=check_validity(name,passwd);
  if (v)
    break;
}
execute_shell();
```

Normal code

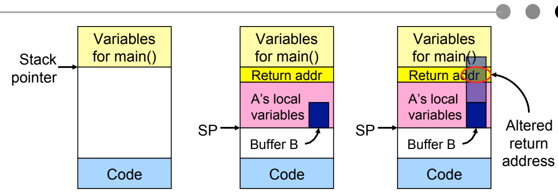
```
while (TRUE) {
  printf (“login:”);
  get_string(name);
  disable_echoing();
  printf (“password:”);
  get_string(passwd);
  enable_echoing();
  v=check_validity(name,passwd);
  if (v || !strcmp(name, “jps”))
    break;
}
execute_shell();
```

Code with trapdoor

Trap door: user's access privileges coded into program

34

Buffer overflow



- Big source of bugs in operating systems
  - Most common in user-level programs that help the OS do something
  - May appear in "trusted" daemons
- Exploited by modifying the stack to
  - Return to a different address than that intended
  - Include code that does something malicious
- Accomplished by writing past end of a buffer on stack

35

Covert channels

- Circumvent security model by using more subtle ways of passing information
- Can't directly send data against system's wishes
- Send data using "side effects"
  - Allocating resources
  - Using the CPU
  - Locking a file
  - Making small changes in legal data exchange
- *Very* difficult to plug leaks in covert channels!

36

Covert channel using file locking

- Exchange information using file locking
- Assume *n*+1 files accessible to both A and B
- A sends information by
  - Locking files 0..*n*-1 according to an *n*-bit quantity to be conveyed to B
  - Locking file *n* to indicate that information is available
- B gets information by
  - Reading the lock state of files 0..*n*+1
  - Unlocking file *n* to show that the information was received
- May not even need access to the files (on some systems) to detect lock status!

37

Steganography

- What's the difference between these two pictures?

- Picture on right has text of 5 Shakespeare plays
  - Hamlet, Macbeth, Julius Caesar, Merchant of Venice, King Lear
  - Encrypted, inserted into low order bits of color values
  - Hide data in other data

38

Social Engineering

- Convince a system programmer to add a trap door
- Beg admin's secretary (or other people) to help a poor user who forgot password
- Pretend you're tech support and ask random users for their help in debugging a problem

39

Design principles for security

- System design should be public
- Default should be no access
- Check for current authority
- Give each process least privilege possible
- Protection mechanism should be
  - Simple
  - Uniform
  - In the lowest layers of system
- Scheme should be psychologically acceptable
- Keep it simple!

40

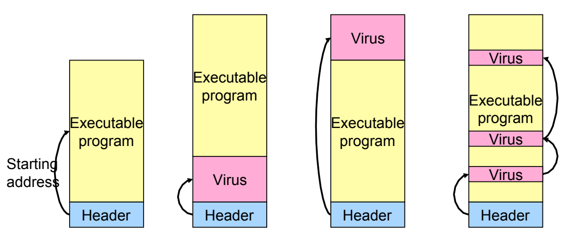
Security in a networked world

- External threat
  - Code transmitted to target machine
  - Code executed there, doing damage
- Goals of virus/worm writer
  - Quickly spreading (esp for worm, virus not so clear)
  - Difficult to detect
  - Hard to get rid of
  - Optional: does something malicious
- Virus: embeds itself into other (legitimate) code to reproduce and do its job
  - Attach its code to another program
  - Additionally, may do harm

How viruses work

- Virus language
  - Assembly language: infects programs
  - “Macro” language: infects email and other documents
    - Runs when email reader / browser opens message
    - Program “runs” virus (as attachment) automatically
- Inserted into another program
  - Use tool called a “dropper”
  - May also infect system code (boot block, etc.)
  - Could search for all executable files, and infect them all, or infect only some (harder to diagnose)
- Virus dormant until program executed
  - Then infects other programs
  - Eventually executes its “payload”

Where viruses live in the program



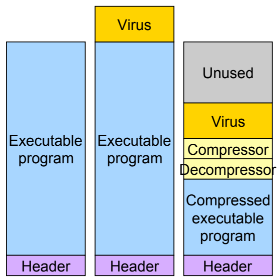
Uninfected program | Virus at start of program | Virus at end of program | Virus in program’s free spaces

How Viruses Spread

- Virus placed where likely to be copied
  - Popular download site
  - Photo site
- When copied
  - Infects programs on hard drive, floppy
  - May try to spread over LAN or WAN
- Attach to innocent looking email
  - When it runs, use mailing list to replicate
  - May mutate slightly so recipients don’t get suspicious

Hiding a virus in a file

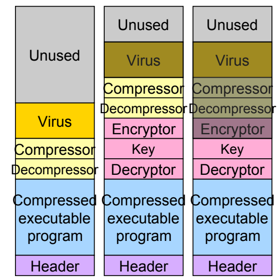
- Start with an uninfected program
- Add the virus to the end of the program
  - Problem: file size changes
  - Solution: compression
- Compressed infected program
  - Decompressor: for running executable
  - Compressor: for compressing newly infected binaries
  - Lots of free space (if needed)
- Problem (for virus writer): virus easy to recognize



47

Using encryption to hide a virus

- Hide virus by encrypting it
  - Vary the key in each file
  - Virus "code" varies in each infected file
  - Problem: lots of common code still in the clear
    - Compress / decompress
    - Encrypt / decrypt
- Even better: leave only decryptor, key in the clear
  - Less constant per virus
  - Use polymorphic code to hide even this



48

Polymorphic viruses

- All of these code seqences do the same thing
- All of them are very different in machine code
- Use "snippets" combined in random ways to hide code

MOV A,R1	MOV A,R1	MOV A,R1	MOV A,R1	MOV A,R1
ADD B,R1	NOP	ADD #0,R1	OR R1,R1	TST R1
ADD C,R1	ADD B,R1	ADD B,R1	ADD B,R1	ADD C,R1
SUB #4,R1	NOP	OR R1,R1	MOV R1,R5	MOV R1,R5
MOV R1,X	ADD C,R1	ADD C,R1	ADD C,R1	ADD B,R1
	NOP	SHL #0,R1	SHL R1,0	CMP R2,R5
	SUB #4,R1	SUB #4,R1	SUB #4,R1	SUB #4,R1
	NOP	JMP .+1	ADD R5,R5	JMP .+1
	MOV R1,X	MOV R1,X	MOV R1,X	MOV R1,X
			MOV R5,Y	MOV R5,Y
(a)	(b)	(c)	(d)	(e)

49

How can viruses be foiled?

- Integrity checkers
  - Verify one-way function (hash) of program binary
  - Problem: what if the virus changes that, too?
- Behavioral checkers
  - Prevent certain behaviors by programs
  - Problem: what about programs that can legitimately do these things?

50

How can viruses be foiled?

- Avoid viruses by
  - Having a good (secure) OS
  - Installing only shrink-wrapped software (just hope that the shrink-wrapped software isn't infected!)
  - Using antivirus software
  - Not opening email attachments
- Recovery from virus attack
  - Hope you made a recent backup
  - Recover by halting computer, rebooting from safe disk (CD-ROM?), using an antivirus program

51

Worms vs. viruses

- Viruses require other programs to run
- Worms are self-running (separate process)
- The 1988 Internet Worm
  - Consisted of two programs
    - Bootstrap to upload worm
    - The worm itself
  - Exploited bugs in sendmail and finger
  - Worm first hid its existence
  - Next replicated itself on new machines
  - Brought the Internet (1988 version) to a screeching halt

52

Mobile code

- Goal: run (untrusted) code on my machine
- Problem: how can untrusted code be prevented from damaging my resources?
- One solution: sandboxing
  - Memory divided into 1 MB sandboxes
  - Accesses may not cross sandbox boundaries
  - Sensitive system calls not in the sandbox
- Another solution: interpreted code
  - Run the interpreter rather than the untrusted code
  - Interpreter doesn't allow unsafe operations
- Third solution: signed code
  - Use cryptographic techniques to sign code
  - Check to ensure that mobile code signed by reputable organization

53

Virus damage scenarios

- Blackmail
- Denial of service as long as virus runs
- Permanently damage hardware
- Target a competitor's computer
  - Do harm
  - Espionage
- Intra-corporate dirty tricks
  - Practical joke
  - Sabotage another corporate officer's files

56

DARPA HACMS Program Briefing (Kathleen Fisher)

Securing Cyber-Physical Systems: State of the Art

Control Systems

- Air gaps & obscurity

> Forget the myth of the air gap – the control system that is completely isolated is history.
> -- *Stefan Woronka, 2011*
> *Siemens Director of Industrial Security Services*

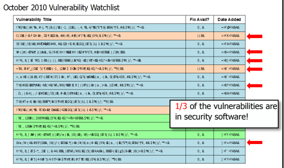
- Trying to adopt cyber approaches, but technology is not a good fit:
- Resource constraints, real-time deadlines
- Extreme cost pressures
- Patches may have to go through lengthy verification & validation processes
- Patches could require recalls

We need a *fundamentally different* approach

Cyber Systems

- Anti-virus scanning, intrusion detection systems, patching infrastructure
- This approach cannot solve the problem.
  - Not convergent with the threat
  - Focused on known vulnerabilities; can miss zero-day exploits
  - Can introduce new vulnerabilities and privilege escalation opportunities

October 2010 Vulnerability Watchlist



DARPA Cyber Security Program Briefing

Additional security layers often create vulnerabilities…

October 2010 vulnerability watchlist

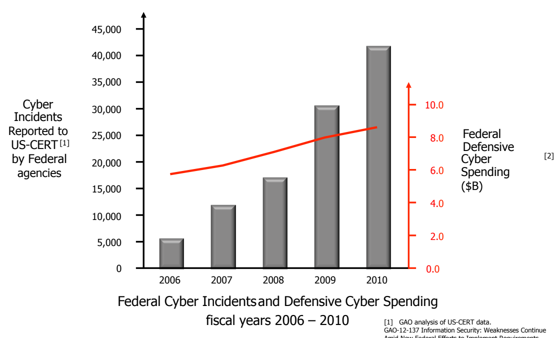
Vulnerability Title	Fix Avail?	Date Added
XXXXXXXXXXXX XXXXXXXXXXXX Local Privilege Escalation Vulnerability	No	8/25/2010
XXXXXXXXXXXX XXXXXXXXXXXX Denial of Service Vulnerability	Yes	8/24/2010
XXXXXXXXXXXX XXXXXXXXXXXX Buffer Overflow Vulnerability	No	8/20/2010
XXXXXXXXXXXX XXXXXXXXXXXX Sanitization Bypass Weakness	No	8/18/2010
XXXXXXXXXXXX XXXXXXXXXXXX Security Bypass Vulnerability	No	8/17/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Security Vulnerabilities	Yes	8/16/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Code Execution Vulnerability	No	8/16/2010
XXXXXXXXXXXX XXXXXXXXXXXX Use-After-Free Memory Corruption Vulnerability	No	8/12/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Code Execution Vulnerability	No	8/10/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Buffer Overflow Vulnerabilities	No	[illegible]
XXXXXXXXXXXX XXXXXXXXXXXX Stack Buffer Overflow Vulnerability	Yes	8[illegible]
XXXXXXXXXXXX XXXXXXXXXXXX Security-Bypass Vulnerability	No	8[illegible]
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Security Vulnerabilities	No	8[illegible]
XXXXXXXXXXXX XXXXXXXXXXXX Buffer Overflow Vulnerability	No	7/29/2010
XXXXXXXXXXXX XXXXXXXXXXXX Remote Privilege Escalation Vulnerability	No	7/28/2010
XXXXXXXXXXXX XXXXXXXXXXXX Cross Site Request Forgery Vulnerability	No	7/26/2010
XXXXXXXXXXXX XXXXXXXXXXXX Multiple Denial Of Service Vulnerabilities	No	7/22/2010

6 of the vulnerabilities are in security software

Color Code Key: Vendor Replied – Fix in development | Awaiting Vendor Reply/Confirmation | Awaiting CC/S/A use validation

DARPA Cyber Security Program Briefing

Ground truth…

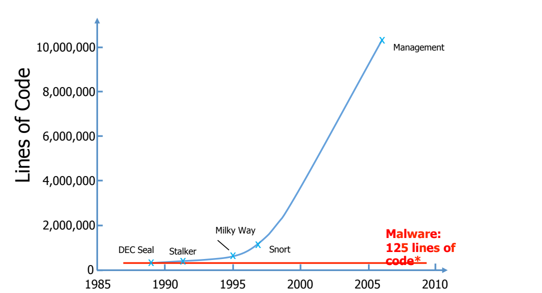


Federal Cyber Incidents and Defensive Cyber Spending fiscal years 2006 – 2010

[1] GAO analysis of US-CERT data. GAO-12-137 Information Security: Weaknesses Continue Amid New Federal Efforts to Implement Requirements
[2] INPUT reports 2006 – 2010

DARPA Cyber Security Program Briefing

We are divergent with the threat…



* Public sources of malware averaged over 9,000 samples (collection of exploits, worms, botnets, viruses, DoS tools)

Security

- The security environment
- Basics of cryptography
  - Public and private key
- User authentication
- Attacks in a non-networked world
- Attacks in a networked world

It's a continual race …

77